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The perception of manoeuvres of moving vehicles. Progress Report VI (Final Report) -

Implications of psychophysical threshold measurements for the night driving situation -

W.H. Janssen

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The perception of manoeuvres of moving vehicles. Progress Report VI (Final Report) - Implications of psychophysical threshold measurements for the night driving situation

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Summary

After a review of the principal results contained in the previous reports in this series a generalized equation is derived which expresses threshold speed in depth for relative movement as a function of observation distance and observation duration. On the basis of this equation calculations are then made to yield values of two important temporal parameters in car-following, viz. 'time until collision' and 'free time'. It is shown that there are circumstances in which these parameters take values which are too short for the driver to escape a collision after he has detected that he is closing on a lead vehicle. Suggestions to improve the car-following situation, in human factors terms, are presented.

De waarneming van manoeuvres van bewegende voertuigen. Voortgangsrapport VI (afsluitend rapport) - Implikaties van psychofysische drempelmetingen voor de situatie van het nachtrijden.

Samenvatting

Nadat een overzicht gegeven is van de belangrijkste resultaten uit de eerdere rapporten in deze serie wordt een gegeneraliseerde vergelijking afgeleid die de drempelsnelheid in de diepte voor relatieve beweging uitdrukt als funktie van observatie-afstand en observatieduur. Op basis van deze vergelijking worden dan waarden berekend van twee belangrijke tijdsparameters in het volggedrag, nl. 'de tijd tot botsing' en de 'vrije tijd'. Het blijkt dat er omstandigheden zijn waarin deze parameters dusdanig geringe waarden aannemen dat een bestuurder niet meer aan een botsing kan ontsnappen nadat hij heeft gedekteerd dat hij op de voorligger inloopt. Suggesties worden gedaan om de volgsituatie te verbeteren in termen van human factors.

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1. Summary of empirical findings from previous reports

The five reports issued in this series have dealt with the psychophysics of night driving, specifically, with a driver's judgment of the distal behavior of a lead car on the basis of proximal changes in its taillight configuration. The introductory section of this final report will be devoted to a summary of the main results that have originated from these psychophysical experiments. It will then be attempted to explore in subsequent sections what implications the findings have for the situation of following a car in darkness, in particular, whether the results could give rise to suggestions that may reduce the relatively large accident-liability statistical records show to be associated with night-time driving.

The experiments that have been done did not originate from any particular view on the process of car-following, nor were they meant to test such views. Their significance as far as car-following theory is concerned lies only in the production of certain parameter values to be substituted in formulations which incorporate driver perception as a variable. Thus, apart from being based on the acceptance of the trivial principle that drivers do attend to a car in front of them every now and then these parameter estimates are atheoretical. They could show, however, that a particular theory is untenable because it makes unrealistic assumptions about a driver's perceptual capacities.

Four of the five progress reports (Harvey and Michon, 1971; Janssen, 1971, 1972a, 1973) have described research on the threshold situation, in which closure or opening relative to a lead car is barely perceivable. The remaining report (Janssen, Michon and Buist, 1971) contained the description of a number of experiments dealing with the suprathreshold case, i.e., it aimed at the derivation of subjective scales for closing and opening rate of a pair of automobile taillights.

In this report we will heavily concentrate on the threshold results at the expense of the scaling data. The theoretical rationale for doing this is that there are good reasons to assume that man is best described as a threshold detector-controller in situations of the kind we deal with (e.g., Rockwell and Snider, 1969).

A more practical reason for concentrating on the threshold case is that speed differences between cars driving in darkness are probably not so large that it is possible to apply the subjective scales derived by Janssen et al (1971). In these studies somewhat unrealistic speeds, sometimes far

over 100 kph, were required in order to determine the shape of the psychophysical scaling function over a reasonable range of stimuli.

The view that threshold performance is the relevant one in the car-following situation should, however, not be considered to imply a denial of the importance of suprathreshold processes in other instances. Overtaking, for example, is an obvious case in which subjective estimates of large speed differences play a major role.

The aim of the experiments performed has not only been to obtain threshold estimates, but also to identify the major perceptual cue in car-following underlying threshold performance (if there is any). A priori there are two important cues which the following driver in darkness might use to judge whether he is moving relative to the lead car. One is a change in the angular subtense of the distance between the lead car's taillights, the other a change in either apparent size or brightness of the lights if there is a speed difference.

It has been demonstrated that the prominent cue to the detection of a speed difference is a change in angle rather than in size or brightness

The logic by which this conclusion was reached empirically was as follows.

First, Harvey and Michon (1971) made threshold measurements in a laboratory setting by having their subjects respond to a pair of lights whose rate of change in angular separation was varied as a function of (simulated) velocity in depth, their apparent size and brightness remaining constant throughout movement. Second, Janssen (1972a) measured thresholds, again in the laboratory, while apparent size-brightness was the cue for relative movement in depth. This was done with lights identical to those used by Harvey and Michon. It appeared that the thresholds in this second situation were very much higher than those found with the isolated cue of change in angular separation. Moreover discrimination of size was found to be superior to brightness discrimination for this type of stimulus (i.e., a target moving in depth continuously).

Consequently it was concluded that a change in angular separation is the prominent cue in the detection of relative speed. A field experiment was subsequently performed which aimed at verifying this conclusion by checking some of the threshold values obtained by Harvey and Michon in a realistic car-following situation (Janssen, 1973). In this experiment the speed difference between a lead car and a following car was selected so as to be equal to the threshold speed obtained in the laboratory ex-

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periment with change in angular separation as a cue and it was observed whether detectability would be at threshold level. It was found that performance was indeed at approximately that level, so that the conclusion from the laboratory studies was not contradicted. Apparently drivers indeed detect relative motion from a change occurring in the angular separation between the taillights of the lead vehicle.

One more experimental result should be mentioned here. Janssen (1971) found that the superposition of a constant lateral velocity upon a simultaneous change in angular separation was grossly degrading to the detectability of the change. This situation corresponds to that in which a lead car is following a course under a certain small angle with a following car's course, such as when it is leaving a motorway via an off-ramp.

On the basis of the threshold values reported by Harvey and Michon (1971) we will now first derive a generalized, smoothed equation expressing the relation between threshold speed, observation distance (headway) and observation duration.

2. Velocity thresholds as a function of headway and observation duration

In the remainings of the report the following symbols will be used:

- d = distance between taillights. All calculations that follow are based on a value of d representative for a car of average dimensions ($d = 1.40$ m). By conversion via angular measures it is possible to use a different value of d as a computational basis (see sect. 5).
- D = distance between cars (headway) at the beginning of the observation interval. In the Harvey and Michon experiment D took values of 40, 80, 160, 320 and 640 m, corresponding to angular separations of 2^{o}, 1^{o}, 30', 15' and 7.5', respectively, for $d = 1.40$ m.
- t = duration of observation interval. The values were 0.5, 1.0, 2.0 and 4.0 sec.
- v_{th} = threshold velocity difference. When referring to an empirical estimate v_{th} is always a geometrical average over a group of subjects.
- α = angle subtended at the beginning of the observation interval (2^{o}, 1^{o}, 30', 15', and 7.5').
- $\dot{\alpha}_{th}$ = angular threshold velocity, considered at the beginning of the observation interval.

Although threshold speeds have been obtained both for the opening and the closure situation, and although the instability of a traffic system

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leading to a rear-end collision must be attributed to an interplay of both opening and closing decelerations and accelerations, the discussion will be restricted to the closure situation. Obviously, closure is the situation which in itself is the more dangerous one from the viewpoint of safety.

Figure 1 summarizes Harvey and Michon's data for closure. Since the log-log plots looked reasonably linear they were fitted by least-squares estimates; the resulting equations were:

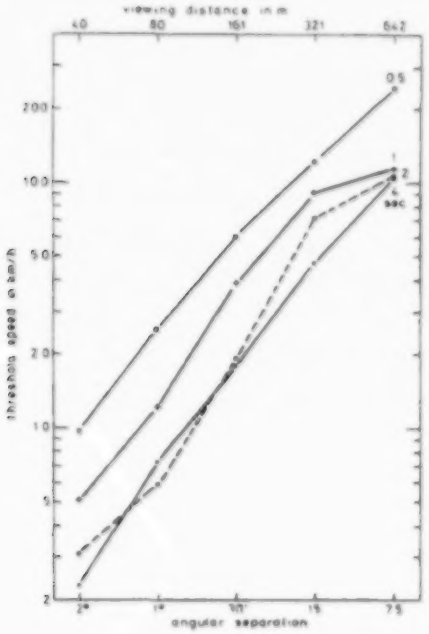

Fig. 1. Mean threshold speed for closure in kilometers per hour as a function of viewing distance for different exposure duration (Harvey and Michon, 1971).

$$(t = 0.5 \text{ sec}) \qquad v_{th} = 0.152\ D^{1.16} \qquad (1a)$$

$$(t = 1.0 \text{ sec}) \qquad v_{th} = 0.079\ D^{1.18} \qquad (1b)$$

$$(t = 2.0 \text{ sec}) \qquad v_{th} = 0.018\ D^{1.38} \qquad (1c)$$

$$(t = 4.0 \text{ sec}) \qquad v_{th} = 0.017\ D^{1.37} \qquad (1d)$$

(v_{th} in kph, D in m)

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Although the exponents in these equations are not identical they were considered to be sufficiently close to each other to permit the use of a single exponent for different exposure durations t in further computations. The value chosen was 1.25, about the average of the four exponents.

We thus take:

$$v_{th} = f(t).\ D^{5/4} \qquad (2)$$

as the idealized, smoothed expression to serve as a computational basis; f(t) is constant for a given value of t. After having refit the original equations (1a) - (1d) to incorporate the idealized exponent the function f(t) can be determined by least-squares. A hyperbolical equation was judged to describe f(t) best:

$$f(t) = \frac{t}{36.72t - 15.17} \qquad (3)$$

Values of f(t) are tabulated below; since f(t) is not dimensionless they are valid if v_{th} is expressed in kph and D in m.

When changing to angular dimensions the time dependentfunction f(t) becomes g(t), which again is not dimensionless.

Since

$$\dot{\alpha}_{th} = \frac{d.v_{th}}{D^2} \qquad (4)$$

(see Harvey and Michon, 1971) we obtain

$$\begin{aligned} \dot{\alpha}_{th} &= g(t).\ D^{-3/4}\ .d \\ &= h(t).d^{1/4}.\ \alpha^{3/4} \end{aligned} \qquad (5)$$

Table I. Values of the coefficient f(t) in Eq. (2)

t (sec)	f(t) $(sec)^{-1}$
0.5	0.157
1.0	0.047
2.0	0.034
4.0	0.030
∞	0.027

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as the idealized equation expressing $\dot{\alpha}_{th}$, instead of v_{th}, as the dependent threshold variable. (The factor h(t) corresponds to g(t) and f(t), but has again different dimensions.) α is the initial viewing angle. An interesting implication of (5) is that the Weber fraction

$$\frac{\dot{\alpha}_{th}}{\alpha}$$

is not constant, but is seen to be linearly related to $D^{1/4}$.

The subject to which the above equations obtain is the average one. However, from the raw data tabulated in the appendices to the report by Harvey and Michon it is apparent that there are large individual differences in the ability to detect motion. It may be observed from these data that there very commonly is a difference of as much as 100% between the threshold values of the most and the least sensitive subjects within an experimental group. We therefore will not only deal with the average subject, but also with the fairly common subject whose thresholds are, let us say, 50% higher. For him Eq. (2) obtains with a factor 1.5 in front.

3. Time until collision and free time after detection

From the threshold data for closure, formalized as eq. (2), estimates may be obtained of two important temporal parameters in car following, viz. time until collision (T_c) and free time after detection (T_f).

In an earlier paper (Janssen, 1972b) a crude expression was already derived for a parameter termed 'time until crash' (or collision), defined as the period of time between the instant the driver has detected that he is closing and the instant that a collision with the lead car will ensue - given that both cars drive on with the same speed. On the basis of Eq. (2) this parameter, T_c, may now be computed somewhat better then in that paper. It follows from:

$$T_c = \frac{\text{distance after detection}}{v_{th}}$$

$$= \frac{D - v_{th} \cdot t}{v_{th}} \quad , \qquad (6)$$

where v_{th} follows from Eq. (2)

Lee (1972) has calculated T_c under the assumption of fixed angular velocity thresholds of 5'/sec and 1^{o}/sec, which he felt would represent a fair estimate of the range that would be encountered in driving in all but dense fog. This is an approximation which is too crude, since angular thresholds are obviously not fixed but are at least a function of the

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initial angle α and of t. Thus Lee's graphs cannot provide very reliable estimates of T_c. Figs. 2 and 3 do the job somewhat better, since the basic equation (2) from which they are derived incorporates both a Weber mechanism and a constant related to t. T_c is shown both for the average observer (Fig. 2) and for the observer whose thresholds are 50% higher than average (Fig. 3).

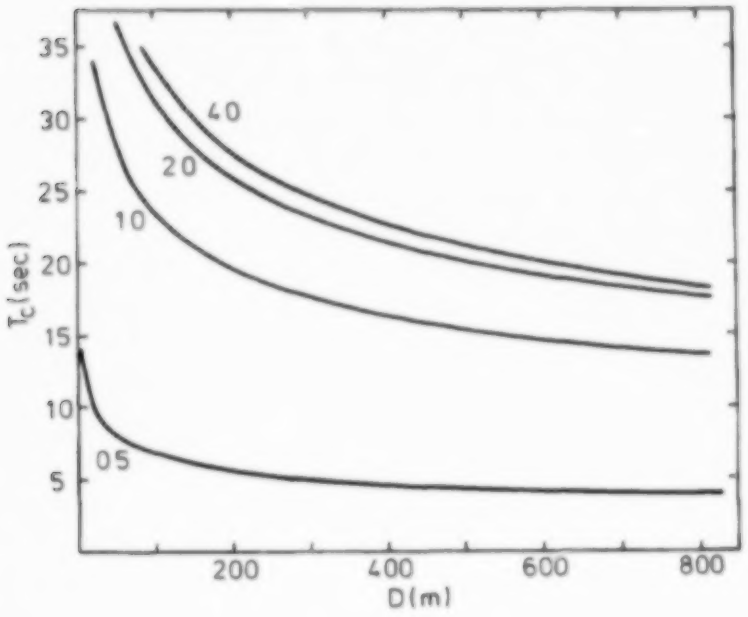

Fig. 2. Time until collision after detection of closure (average observer).

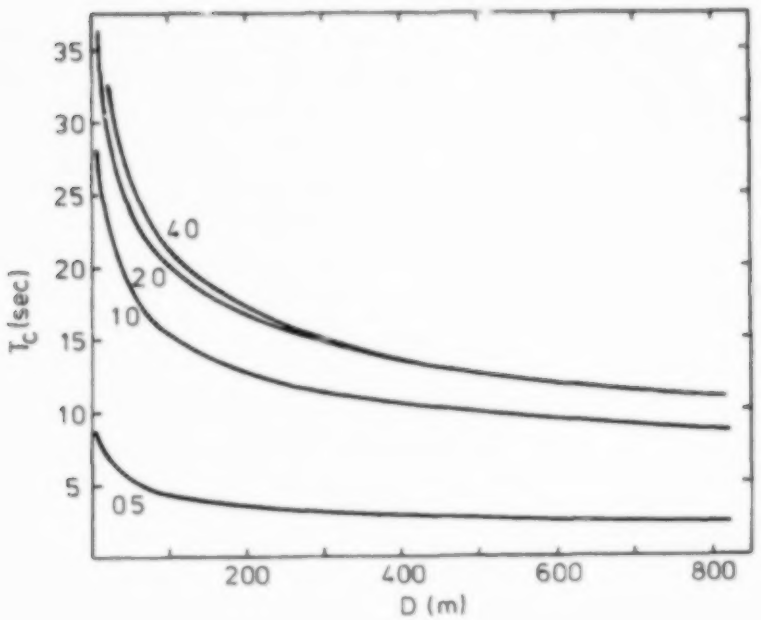

Fig. 3. Time until collision after detection of closure (observers with thresholds 50% higher than average).

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The remarkable feature appearing from these graphs is that T_c grows with decreasing viewing distances and drops to rather low values at the larger viewing distances. Thus, owing to the nonlinearity of the relationship between v_{th} and D it appears that following a lead car at a short distance by keeping relative movement at threshold is considerably safer than following it so at a long distance. This conclusion stands up even if we recognize that the speed differences required to generate the right-hand parts of the curves in Figs. 2 and 3 are unrealistically high. In particular, of course, the conclusion is seen to bear on observers with low movement sensitivity.

Not all of the interval T_c can be spent by the driver in merely thinking what he should do. If the driver is to avoid collision with the lead car there is an ultimate point in time within T_c at which maximum braking force must be applied. Free time T_f is defined as the interval from the moment the driver has detected he is closing until the moment he should apply maximum braking force (which at its utmost may be 1 g) in order to avoid collision.

Although the definition of T_f strictly applies only to the case in which none of the vehicles take any action until the critical moment of full braking it is also interesting to see what becomes of T_f if the lead car changes its movement after the detection of closure has taken place. In particular the case of deceleration would have important consequences to T_f.

Consider, however, first the case in which both vehicles continue their journey with the speeds they had at the beginning of the observation interval t. In order to avoid collision it is necessary for the following car to (at least) reduce its speed to that of the lead car. Take a (<0) to be the deceleration applied by the following car. The reduction of the following car's speed to that of the lead car then takes $- v_{th}/a$ sec.

This value must be subtracted from the value of the time until collision T_c as given by Eq. (6). Moreover a certain interval should be subtracted from T_c which it takes the driver of the following car to initiate his braking reaction. A reasonable estimate of this interval is of the order of 0.7 sec (Lee, 1972). We find:

$$T_f = T_c + \frac{v_{th}}{a} - 0.7 \text{ sec} \qquad (7)$$

($a<0$, $v_{th} > 0$)

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Values of T_f computed from Eq. (7) are shown in Figs. 4, 5, 6 and 7, both for average and underaverage individuals, and for two values of a(-4 and -7 m/sec^2).

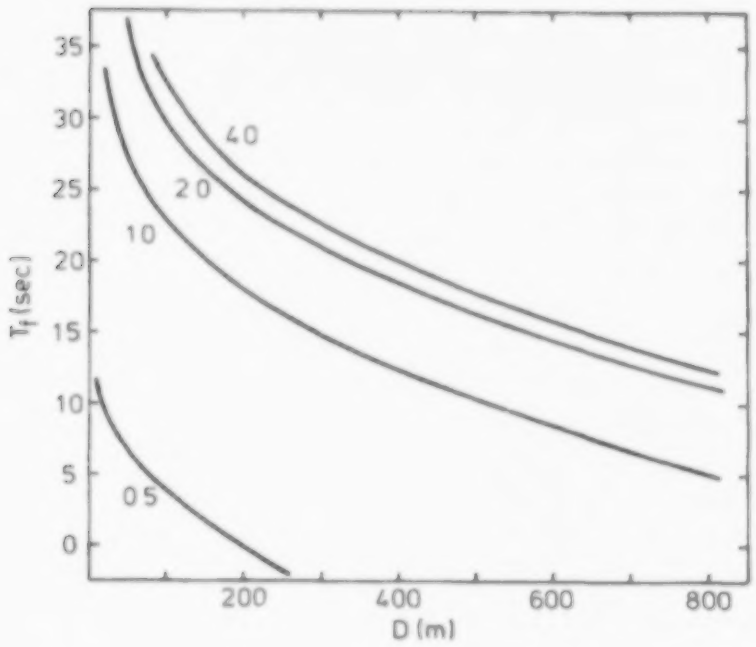

Fig. 4. Free time after detection of closure (average observer, deceleration - 7m/sec^2).

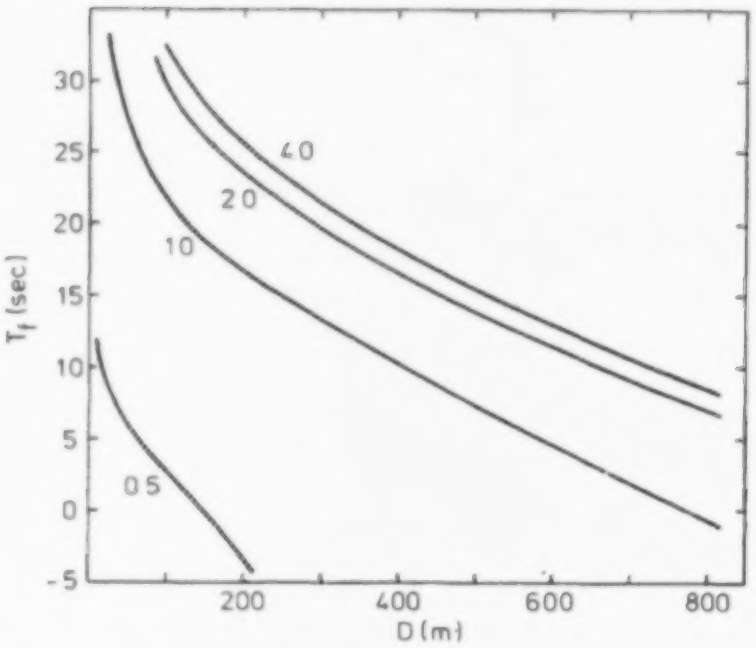

Fig. 5. Free time after detection of closure (average observer, deceleration - 4m/sec^2).

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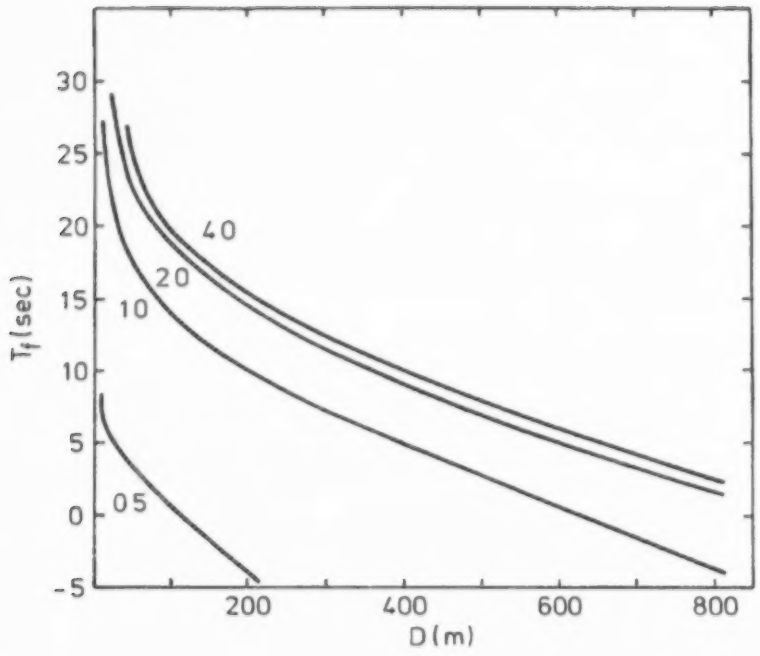

Fig. 6. Free time after detection of closure (observer with thresholds 50% higher than average, deceleration -7m/sec^2).

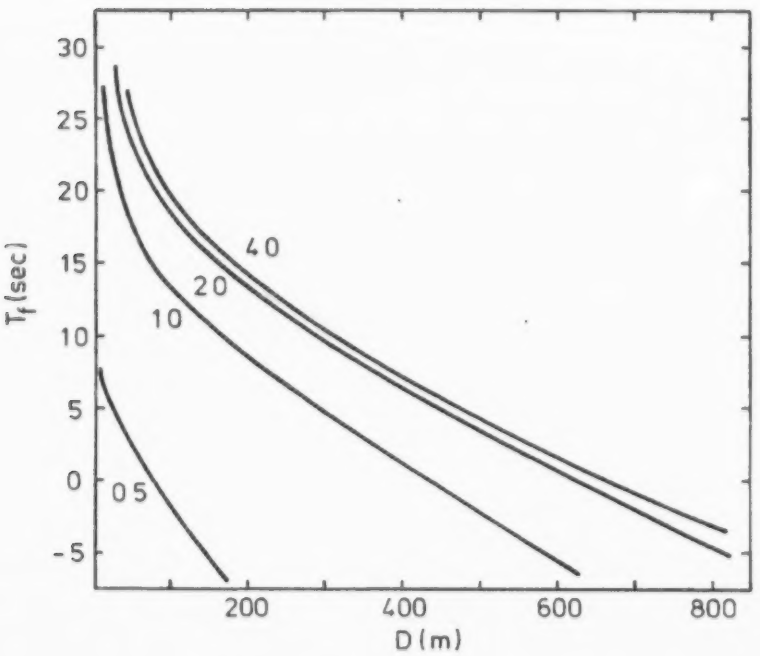

Fig. 7. Free time after detection of closure (observers with thresholds 50% higher than average, deceleration -4m/sec^2).

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As with the graphs for T_c the steep rising of the curves with small viewing distances and their gradual drop at the larger distances is clearly apparent.

Now consider the case in which the lead vehicle starts decelerating at the very moment the driver of the following car has detected the existence of a speed difference.(There is nothing special about the deceleration supposed to take place at this moment, except that it makes computations slightly simpler).

Denote the magnitude of the lead car's deceleration by b and suppose that it is maintained for a period t^* (we require that t^* is much smaller than the time until collision T_c in order for the situation to make sense). During the period of deceleration the speed difference between the vehicles will change from v_{th} to

$$V^* = v_{th} - b.t^* \quad (b < 0) \tag{8}$$

What about the distance D^* between the vehicles after the interval t^*? Obviously D^* equals the distance at the moment of the detection of a speed difference minus the difference between the distances both vehicles have travelled during the deceleration interval. This difference is seen to equal

$$v_{th}.t^* - \tfrac{1}{2} b.t^{*2} \tag{9}$$

so that the distance between the cars after the deceleration interval is

$$D^* = \frac{D - v_{th}.t}{v_{th}} - v_{th}.t^* + \tfrac{1}{2} b.t^{*2} \tag{10}$$

Time until collision is then seen to be equal to

$$T_c = \frac{D^*}{v^*} + t^* \tag{11}$$

(Observe that t^* must be added because the observer in the following car has already survived this deceleration interval).

In order to compute T_f we merely have to subtract from T_c the time it takes to reduce the speed difference to 0 after the lead car's deceleration, and also the time it takes to initiate the braking reaction. This yields:

$$T_f = T_c - \left(\frac{v_{th} - b.t^*}{a}\right) - 0.7 \text{ sec} \tag{12}$$

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From this expression one may get a feeling of how disastrous even a small deceleration of the lead car, applied for only a few seconds, may be on the available free time. Fig. 8 shows, as an example, the values of T_f resulting from a deceleration of -2 m/sec^2 maintained during 2 sec and compares these to the values obtained in the stationary situation without deceleration (Fig. 4). The effect is particularly impressive at the smaller distances, since here the change in relative speed caused by the deceleration is large compared to v_{th}. For an observation interval of over 0.5 sec T_f is seen to have a maximum at a headway of about 200 m.

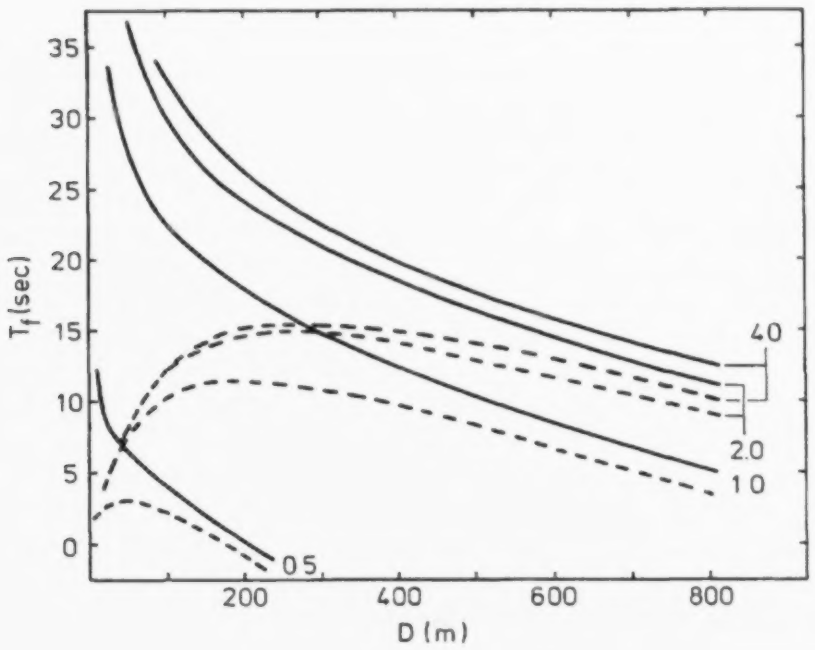

Fig. 8. A comparison between free times with and without deceleration of the lead car. Dotted line: with deceleration of -2m/sec^2 maintained during 2 sec. The picture is valid for observers of average sensitivity.

4. The size of the natural sampling interval

The functions for T_c and T_f show that the largest increase in these temporal parameters takes place when exposure duration goes up from 0.5

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to 1.0 sec. Relatively little improvement is found if t takes values of over 1.0 sec.

This brings us to the question of what the sampling rate of visual information during driving actually is. Since drivers surely do not continuously pay attention to the road in front of them one would like to have information on how often they do pay attention to environmental features and, still more important for present purposes, what the size of the sampling interval is.

The literature, unfortunately, is lacking on this point. Although a promising approach to visual sampling during driving has been developed by Senders et al (1967) it has not yet been used so as to yield results that are appropriate to the present issue. What Senders et al. did was to study sampling rates for given vehicle speeds by periodically raising (at the subject's desire) and lowering a visor attached to a helmet that subjects wore during driving. They used fixed viewing durations (of 0.25, 0.50, and 1.00 sec) and measured the duration of periods of occluded vision. This is a procedure which does not yield an estimate of the natural sampling duration. The reverse procedure, i.e. having a subject drive with unobstructed vision until he indicates that he can do without vision for a while could yield an estimate of sampling durations (although this would be a somewhat artificial thing to do for the subject).

For the time being we have only some pilot studies by Senders et al. to rely on. From these studies it appears that a 'sampling episode', consisting of a 0.5 sec sampling interval every 3 sec, can be identified.

5. The effect of taillight separation on speed thresholds

The values of collision and free intervals displayed in Figs. 2-8 assume that d, the metric distance between taillights, is 1.40 m. Since the detectability of relative movement is based on angular cues (see Eq. (4) and (5)) we may ask what the effect of variation in d is on the speed thresholds and, consequently, on the temporal parameters of relevance in car-following. What is the effect on v_{th} if we change d into k.d, all other things remaining equal?

In order to assess this effect the requirement to be kept in mind is that the movement in depth of the lights (now separated by a distance k.d) must possess a speed which is sufficient to bring angular velocity at the threshold level associated, through the Weber mechanism, with the initial angular separation between the lights.

The relationship between angular velocity and initial angular separation we already know from the experiments in which d was, for convenience, cho-

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sen to be 1.40 m. Hence, we may derive an expression for the size of the ratio of the threshold speeds for any two values of the taillight distance which differ by some factor k.

To this purpose compare three situations (see Fig. 9). First there is

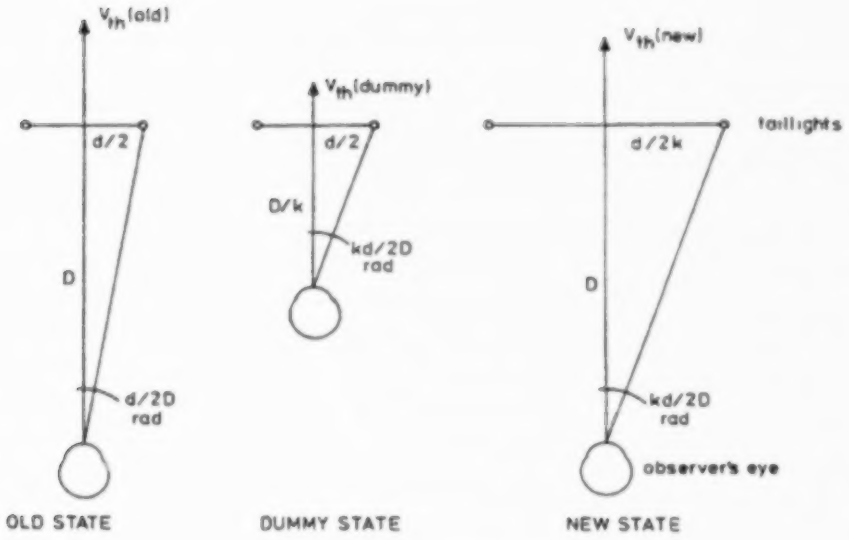

Fig. 9. Computation of the effect on the threshold for closure of a change in taillight separation by a factor k.

the situation with the 'old' taillight separation d, observed from a distance D and resulting in a speed threshold v_{th} (old). Second, there is the situation with the 'new' taillight separation k.d, again observed from a distance D, and resulting in a speed threshold v_{th} (new). These are the two situations we wish to compare, i.e., we want to know the ratio v_{th} (new)/v_{th}(old).To this means we need a third situation in which the taillight separation is the old d, but in which the initial angle between the taillights is equal to that in the 'new' situation. This 'dummy' situation we need in order to know the required angular threshold going

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with a particular initial angle, which we can then translate back to the 'new' situation. This means that taillights in this third situation must be at an observation distance D/k; there is a speed threshold v_{th} (dummy).

Now we are able to write expressions for the speed thresholds in each of these three situations by making use of the basic Eq. (2) and also of the expression relating $\dot{\alpha}_{th}$ to distal variables (Eq. (4)).

In the 'old' situation we have

$$v_{th}\ (\text{old}) = f\ (t)\ .\ D^{5/4} \tag{13}$$

From the proximal identity of the 'new' and the 'dummy' states follows the requirement that

$$\dot{\alpha}_{th} = \frac{d.v_{th}\ (\text{dummy})}{(\frac{D}{k})^2} = \frac{k.d.v_{th}\ (\text{new})}{D^2} \tag{14}$$

from which we find that

$$v_{th}\ (\text{new}) = k.v_{th}\ (\text{dummy}) \tag{15}$$

This says simply that if we double both the distance between lights and the observation distance at the same time, for example, we will need twice the original velocity in depth to maintain the same angular velocity. Since we have

$$v_{th}\ (\text{dummy}) = f(t).(\frac{D}{k})^{5/4} \tag{16}$$

and, consequently,

$$v_{th}\ (\text{new}) = k.\ f(t).\ (\frac{D}{k})^{5/4} \tag{17}$$

it follows by combining Eqs. (13) and (17) that

$$\frac{v_{th}\ (\text{new})}{v_{th}\ (\text{old})} = k^{-1/4} \tag{18}$$

This equation gives the desired ratio of the sizes of the threshold speeds after a certain change in d. We may calculate, for example, that reducing d by 50% increases threshold speed by 19%, or that doubling it decreases threshold speed by 16%. Also we may observe that the factor 3 by which automobile taillights distances may differ (from $\pm$ 0.75 to $\pm$ 2.25 m) will cause the smaller cars to have a threshold speed for detection of their relative movement in the dark which is $\pm$ 30% higher than that of their big

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brothers. Obviously this implies a severe reduction in the temporal parameters T_c and T_f. One might conclude at once that making intertaillight separation as large as possible would be a recommendable thing to do.

6. Conclusions from the calculation of temporal parameters

The following may be concluded from the calculations on temporal parameters in car-following which have been presented:

- Both for individuals of average and underaverage sensitivity to relative motion there are likely to occur situations in night driving in which collision with a lead vehicle is a real threat.
- Factors that in particular will increase the risk of a collision are:
  (1) decreased braking power of the following car, such as occurs when roads are wet;
  (2) manoeuvres of the lead car which involve a deceleration, even if it is small and lasts only for a brief period;
  (3) a small intertaillight separation of the lead car.
- It is therefore required that measures are taken which have the net effect of improving a driver's ability to detect a lead car's relative motion. In other words, we must believe there is a real problem to the driver in the situation, and in order for him to survive it should be solved.

A few suggestions to improve upon the existing situation are listed in section 7. It is realized that requirements from other problem areas will and must interfere and interact with these suggestions. More comprehensive treatments of the problem of vehicle lighting and signaling systems are given by Mortimer (1970) and Roszbach (1972).

7. Improving the capacity to detect lead car manoeuvres

Three ways can be distinguished in which the problem of raising detectability capacity could be approached. First, the possibility of training drivers so as to increase their sensitivity could be explored. Second, there is the possibility of developing new systems, demanding major modifications of current vehicle design, which inform surrounding traffic of a vehicle's ongoing or planned manoeuvres. Third, one might try to modify existing vehicle lighting systems in a relatively minor way so as to be better adapted to the needs of drivers of fellow vehicles.

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Between the second and the third alternative there is, of course, only a gradual difference.

Improving sensitivity by systematic training is a subject which has not attracted much attention in the literature. This apparently is because the detection of relatively simple stimuli is not considered to be a skill which can be learned and developed. Another reason why the literature is scarce is that researchers working in the field of detection are usually interested only in stable asymptotic performance and have developed a habit of throwing the learning portion of their data away.

Blackwell (1953) is an exception to the rule. In a large-scale study of visual detection he included an investigation in which he found that subjects displayed training effects in the detection of a spot of light which extended to 6 or 7 sessions of 2 hours each. The final effect was a decrease in threshold luminance of the order of 25 to 30%.

Despite the fact that Blackwell's experimental set-up differed a great deal from ours there is reason to hope that training might improve driver's sensitivity to motion, the more so since Blackwell's subjects did not receive any systematic training but were left at themselves. However, since basic data are still essentially lacking it is difficult to see what form such a training for drivers could possibly take and how it should be incorporated into driver education as a whole.

The second alternative, the development of radical new systems aimed at improving the perceptibility of vehicle manoeuvres, has already been under exploration for several years now. Although it is probably still too early to reach a definitive conclusion the evidence as yet is that this approach has appeared a rather fruitless one in terms of the probability of one of the constructions developed to be ever implemented. Contributing to this impression are the failures to be considered realistic solutions of such reasonable proposals as the application of Doppler radar in order to force the driver into maintaining a fixed headway distance, the application of a signal system which warns for ongoing decelerations and acceleration (Michaels and Solomon, 1962), and the application of signal systems which indicate the severity of braking (e.g., Rutley and Mace, 1970).

To the present writer it appears that the direction a solution should take is to improve upon the vehicle-lighting system as it exists today. The following, admittedly rather elementary, suggestions seem worth considering.

First, taillight separation should be standardized. This is not an advice based so much on our own findings as it is on the general consideration

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that a standard separation would help drivers in judging vehicle manoeuvres. In cars as they are found today distance between taillights may vary by no less than a factor 3 (from ± 0.75 to ± 2.25 m). From the point of view of human engineering this is a bad state of affairs.

Second, taillight separation should be as large as possible. The reason is (see section 5) that speed thresholds decrease with increasing d. d. Third, vehicles which presently have only one taillight (motorcycles) should have two. The reason is that the detection of relative speed is easier from angular than from size-brightness cues. Awaiting the implementation of this recommendation one should concentrate on increasing the size of the taillight rather than its brightness. This is because it appeared from the experiment on the efficiency of the size-brightness cue (Janssen, 1972a) that size discrimination for a moving source is superior to brightness discrimination. This implies that it is valuable to guarantee that a light retaints its identity as an area source as long as possible.

8. Testing car-following theories

We will finally try to show how our threshold data may be used to decide between some of the theories of car-following that exist.

Car-following theories can be divided into two groups. Macroscopic theories consider the flow of traffic in analogy to the physics of compressible fluids and hydraulics. Theories on the microscopic level, on the other hand, try to predict the properties of traffic flow by a summation of effects supposed to occur at the level of the individua-driver.

Not surprinsingly the traffic psychologist is mainly interested in theories of the microscopic kind. He should consider it his task to determine which cues a driver employs in order to act, in a way to be specified, upon the main dependent variable of all car-following theories, viz. the acceleration of the following car.

Nowadays there exists a consensus among those concerned with microscopic theories that a change in visual angle subtended by the lead car is about the most important cue instigating action from the part of the driver of the following vehicle. Opinions split, however, when it comes to the question of how the perception of a change of this kind is translated by a driver into a vehicular action. Some researchers (e.g., Todosjev, 1965; Michaels, 1963) propose that acceleration is applied at

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the instant relative speed between cars reaches the threshold level. According to Todosiev's (1965) action-point model the driver then performs an acceleration which is just above his threshold for linear acceleration (approximately 0.01 g).

Other researchers, however, (e.g. Pipes, 1967) have described car-following as a suprathreshold process. Thus they have stated, for example, that the acceleration selected by the following driver is proportional to his perceived rate of change in visual angle and is not necessarily at threshold level.

The first group of theories, those describing the driver as a threshold-controller, can be tested for its applicability to the night driving situation with the help of the threshold data gathered in the present project. The procedure for a field test would amount to the creation of a situation known from these data to call on the driver's threshold capacity. Reading the acceleration he selects in that situation would then give the necessary datum to decide on the validity of threshold controller theories for night driving.

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